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A COMPARISON OF TIME DIVISION MULTIPLEX DATA BUSES BASED ON COMPUTER SIMULATION

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This report compares waveforms, signal losses, and stub impedances for three computer simulated time division multiplex buses. Two of the simulations use coupling transformers to judiciously mismatch the stubs to the main bus. The third (and superior) configuration accomplishes the required mismatch by using a higher characteristic impedance wire for the stubs with no coupling transformer.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION I

INTRODUCTION

The first Air Force Standard for an Airborne Multiplex Bus System, MIL-STD-1553 (USAF), (1) was issued in August of 1973. This standard was the result of the work of the Multiplex Bus Committee at Wright-Patterson Air Force Base. The Committee was composed of members from ASD, AFAL, AFFDL, and other members of the Wright-Patterson AFB complex. The initial work of the Committee was critiqued by other Air Force organizations such as ESD (and MITRE) and by industrial organizations before the standard was issued. Nevertheless, no one had built a system which conformed to the standard at the time that the standard was issued. So the standard was thought of as a "straw man", representing the best thinking within the Air Force and industrial community, but unproven in practice.

There were reasons to question certain of the requirements stated by the standard at the time it was issued. A number of organizations, including MITRE, had begun to perform measurements on various laboratory mock-ups of a multiplex bus. In the course of making the measurements, waveforms were observed that were severely distorted. At some points on the bus the signal nearly vanished--apparently as a result of reflections--and other anomalies occurred which strongly suggested the need for further experimental and theoretical work.

In February 1974 MITRE made available to the Multiplex Bus Committee preliminary laboratory measurements from examinations of digital signal transmissions in shielded, twisted cables. At the same time MITRE prepared a digital computer simulation (2) of the multiplex bus. The same experiments which had been run in the laboratory were simulated on the digital computer with extremely good correlation. In this way MITRE gained confidence that the digital computer simulation was an effective tool. The major source of error seemed to be the lack of accuracy with which cable and transformer characteristics could be measured.

MITRE has continued to use the computer simulation and to add various improvements. The simulation is capable of specifying a transformer at both the stub-to-bus junction and at the other end of the stub. A detailed equivalent circuit is used for each transformer, and this permits the evaluation of changes in transformer parameters. The simulation also permits varying stub length, stub spacing, number of stubs, main bus length, isolation resistors, cable characteristics, input waveform, location of transmitter stubs, main bus terminations, and transmitter receiver impedances.

As a result of both laboratory work and the computer simulation, it has become clear that a twisted shielded pair multiplex bus which must transmit signals in either direction over all parts of the main bus and stubs requires a series of compromises to provide optimum transmission of data. The problem becomes one of judiciously mismatching the stubs to the bus.

MITRE initially ran its experiments without transformers at the stub-to-bus junction. The stub under these conditions presented a relatively low impedance to the bus--between 400 and 500 ohms. When transformer coupling is used at the stub-to-bus junction, almost any reasonable stub impedance can be obtained. At least one industrial organization suggested to the DAIS (Digital Avionics Information System) Program Office that a transformer with a turns ratio of 2.5 to 1 be used at the stub-to-bus junction and another transformer with a turns ratio of 1 to 1.85 at the other end of the 20 foot stub. Simulations based on this type of transformer coupling indicate potential difficulties with waveforms in certain portions of the bus. As an alternative, MITRE has investigated the possibility of using a cable with a higher characteristic impedance for the stubs. Simulations were run using a main bus cable with a characteristic impedance of 71 ohms and stub cable with a characteristic impedance of 200 ohms. No transformer was used at the stub-to-bus junction. The results of these simulations are very encouraging. Compared to the transformer coupled stubs, the waveforms are much improved, the power loss between transmitter and receiver is reduced, and the transformer, another part which might fail and a possible source of noise, is no longer required.

High characteristic impedance wire is available from Belden Cable Company, Richmond, Indiana under catalogue number 9851. This is a twisted shielded cable with a 200 ohm characteristic impedance. It is solid wire rather than stranded, but should serve well for laboratory purposes. As soon as possible, laboratory experiments

will be run at MITRE to confirm that the computer simulation is reliable for high characteristic impedance cable.

As this report is being published, another proposed standard is being written. This is to be a Tri-Service Standard for airborne multiplex buses, superseding MIL-STD-1553. These standardization activities emphasize the need to quickly disseminate information of the type contained in this report.

The purpose of this report is to present a comparison of simulation results for transformer coupled stubs and stubs using a high characteristic impedance cable.

The conclusions of this report are presented in Section II. Section III presents a technical discussion of the simulation algorithm and the detailed data from the simulations.

SECTION II

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are drawn on the basis of computer simulations. The detailed parameters used in the simulations are tabulated in Table II of Section III.

1. The simulations corroborate the results cited in B. Mahler's recent report, ESD-TR-75-52 (3), i.e., that the impedance which the stub presents to the main bus should be between 750 and 1500 ohms for minimum transmitter to receiver losses.

2. When the cable of the stubs only is changed from that having a characteristic impedance of 71 ohms to a cable with a 200 ohm characteristic impedance, no transformer is required to provide a stub impedance in the optimum range. For the particular simulations which were run, the change in cable also resulted in significantly cleaner waveforms at the receivers and a transmitter to receiver loss which was lower by at least two to four db.

3. Removal of the stub-to-bus junction transformer is desirable. The transformer is an additional component with a failure rate which increases the risk of system failure. It adds to the size, weight, and cost of the bus. And, even though it is shielded, it acts as an antenna to collect ambient noise and funnel it into the bus, and vice versa. If it can be removed at the cost of using two types of bus wire instead of one, this is worth investigating.

The following recommendations are based upon the above conclusions:

1. Paragraph 4.2.5.4.4 of MIL-STD-1553 should be changed to read: "4.2.5.4.4 Input Impedance. The MTU input impedance, when the MTU is not transmitting, or has the power removed, shall be a minimum of 750 ohms at a frequency of 1 MHz. This impedance is that measured line-to-line at point 'A' on Figure 7."

2. Paragraph 4.2.4.2, Characteristic Impedance, of MIL-STD-1553 should be changed to permit the use of high characteristic impedance cable for the stubs.

3. Paragraph 4.2.5.1, Circuit Configuration, and Figure 7 of MIL-STD-1553 should be changed to permit the system designer to omit the transformer at the stub-to-bus junction.

4. Changes similar to those suggested above should be made on the proposed Tri-Service Specification.

SECTION III

THE SIMULATION RESULTS

Description of the Multiplex Bus

The multiplex bus which is under investigation is described in detail in Reference 1. It consists of a main bus with multiple stubs of shielded twisted pair cable. The cable length modeled in the simulations is 250 feet. Thirty-two stubs, each of twenty foot length, connect the main bus to the controller and to the remote terminals. Twenty feet is the maximum stub length permitted by MIL-STD-1553, and this figure was used in the calculations because long stubs tend to aggravate the impedance matching problem. The ends of the main bus are terminated in resistors which match the characteristic impedance of the bus in order to prevent energy reflections at the ends of the bus.

In order to prevent an electrical short on one of the stubs from causing the entire bus to fail, 54 ohm isolation resistors are placed in each conductor of each stub at the point where the stub is joined to the main bus. Details of the stub are shown in Figure 1. For a long stub (greater than one foot in length), Reference 1 requires a coupling transformer adjacent to the isolation resistors at the stub-to-bus junction and another coupling transformer at the transmitter/receiver end of the stub.

Three separate cases representing different multiplex bus designs were simulated, and the results are presented in this report. The first case used stubs with transformer parameters which had been suggested by a multiplex bus component manufacturer. A step-up transformer with a ratio of 2.5:1 was used at the stub-to-bus junction to increase the impedance seen by the bus and a transformer having a turns ratio of 1:1.85 was placed at the transmitter/receiver end of the stub to aid in keeping the lines balanced to ground and to match the receiver resistance to the line. An equivalent transformer circuit is shown in Figure 2, and Table I lists in detail the parameters for all of the transformers. The stubs of the first case were terminated with a receiver resistance of 3730 ohms.

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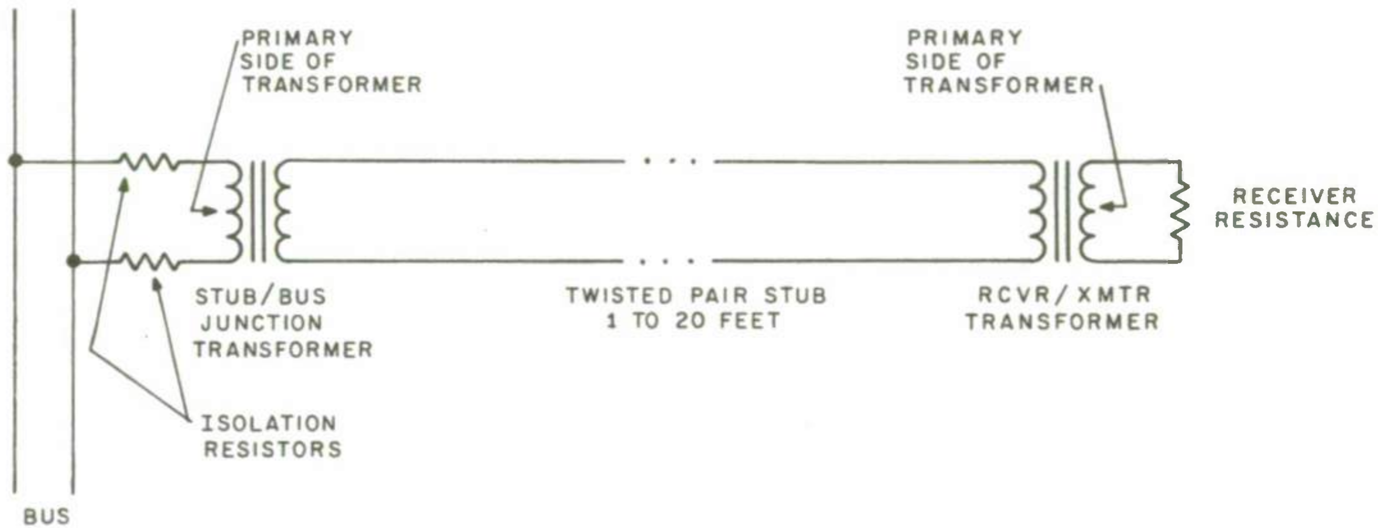

Figure 1 DETAILS OF A STUB

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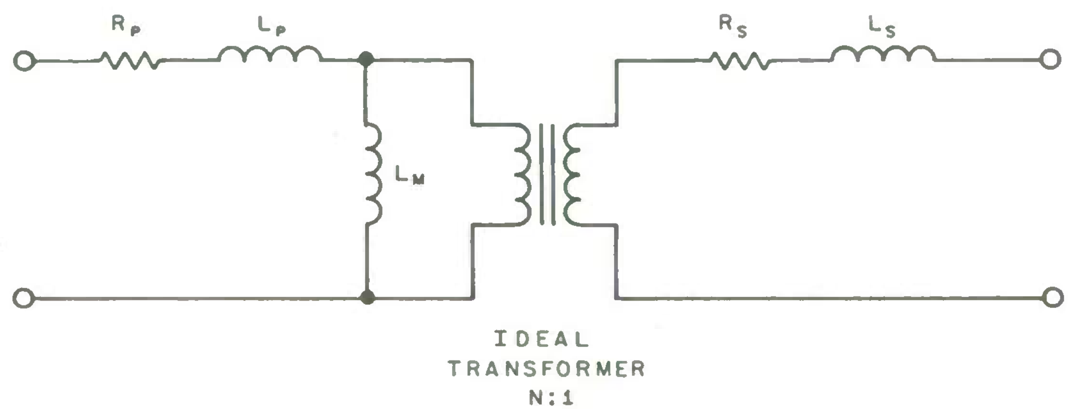

Figure 2 EQUIVALENT TRANSFORMER CIRCUIT

TABLE I

Transformer Parameters

	Transformer A	Transformer B	Transformer C
Turns Ratio, n	2.5:1	1.85:1	1:1
Primary Series Resistance, Rp	14 ohms	14 ohms	14 ohms
Primary Leakage Inductance, Lp	7 h	7 h	7 h
Secondary Series Resistance, Rs	5.6 ohms	7.6 ohms	14 ohms
Secondary Leakage Inductance, Ls	1.1 h	2.1 h	7 h
Magnetizing Inductance, Ln	10mh	10mh	10mh

The transformer parameters shown in Table 1 are either the same as or derived from a transformer, Part No. PE5163, made by Pulse Engineering Incorporated in Santa Clara, California. These parameters were chosen because MITRE had used this transformer in experimental work in the laboratory and it offered a physically realizable example on which to base calculations. Many other transformer designs are possible and consideration should be given to using the simulation program to determine the effect of variations in these parameters.

The second case used the same bus and the same transformers as case 1 but the receiver load resistance was changed to 1,000 ohms.

The third case used a different cable for the stub than that used for the bus. The cable of the main bus in all cases was the same type as that used on the B1, very similar to an RG108 cable, with a characteristic impedance of 71 ohms. For the third case the characteristic impedance of the cable in the stubs was changed to 200 ohms. In addition to this, no coupling transformer was used at the stub-to-bus junction, and a 1:1 transformer, transformer C in Table I, was used at the transmitter/receiver end. A load resistance of 1,000 ohms was used in this case.

A tabulation of the cases considered is shown in Table II for quick reference.

TABLE II

Summary of MUX Bus Parameters

	Case 1	Case 2	Case 3
Characteristic Impedance of Main Bus Cable	71 ohms	71 ohms	71 ohms
Length of Main Bus	250 ft	250 ft	250 ft
Number of Stubs	32	32	32
Length of Stubs	20 ft	20 ft	20 ft
Characteristic Impedance of Stub Cable	71 ohms	71 ohms	200 ohms
Value of Each Isolation Resistance	54 ohms	54 ohms	54 ohms
Stub-to-Bus Transformer	Transformer A (Table I)	Transformer A (Table I)	None
Receiver Transformer	Transformer B (Table I)	Transformer B (Table I)	Transformer C (Table I)
Receiver Resistance	3730 ohms	1000 ohms	1000 ohms

The Conflicting Requirements of a Multiplex Bus

A multiple subscriber time division multiplex bus design requires very careful tradeoffs. In order to minimize errors in data transmission, the designer would like a high signal to noise ratio. This requires low electrical noise in the usual sense as well as low pulse distortion caused by reflections and ringing of reactive circuits. Therefore, the main bus is terminated at each end by a resistor which matches the characteristic impedance of the bus. With no stubs attached, the main bus then looks like an infinite length transmission line, and there are no disturbing reflections. However, when stubs are connected across the bus, the bus is loaded locally, and a mismatch with accompanying reflections results. To minimize the problem of reflections, the designer would like to make each stub present a very high impedance to the bus. At the same time, however, he wants to divert power to each receiver in order to detect the signal. For the simplest detection, the designer would like as much power as possible to reach each receiver. This implies a low stub impedance which, when placed across the bus, causes significant reflections because of the impedance mismatch.

Two other design goals further complicate the problem. The designer would like to use as small a transmitter power as possible to minimize the size of generators, heating, and potential EMI problems. He would also like to introduce isolating impedances at strategic places throughout the network so that if battle damage shorts out a portion of the network, it will not cause the whole network to fail. The isolation resistors at each stub-to-bus junction, mentioned in the previous section, perform this function.

The system designer must adjust stub parameters to provide the best signal to noise ratio consistent with his other constraints. To do this he needs a better understanding of the ways in which he can control stub impedances and the effect of such control on waveform distortion.

The Spectrum of Multiplex Bus Signals

In order to place in proper perspective the relative importance of bus parameters at different frequencies, a spectrum analysis was made of the transmitter waveform. Figure 3 shows the power spectral density of an average 20-bit word. The highest densities lie between dc and 2 MHz with peaks at about 300 KHz and 800 KHz.

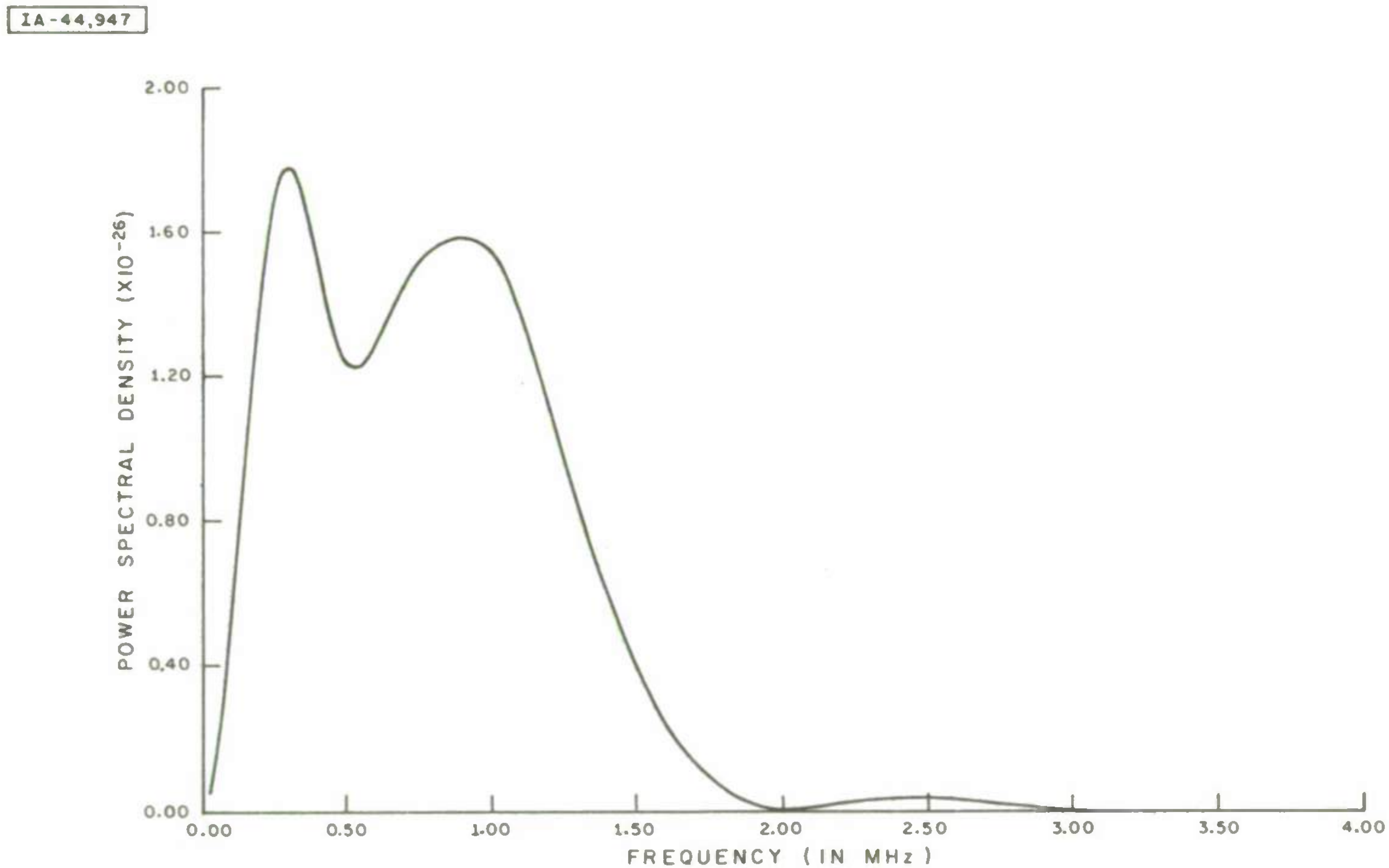

Figure 3 POWER SPECTRAL DENSITY OF AN AVERAGE DATA WORD

The Manchester II waveform produced by the transmitter is symmetrical with respect to the time axis, so it has no DC component, and little of the energy of the waveform exists at the low frequency. This is shown clearly by Figure 4 which presents a cumulative distribution of energy for the first 100 KHz. Note that less than 2/10 of 1 percent of the energy appears below 50 KHz and less than 1 percent below 100 KHz. One suspects that signal components below 50 KHz and probably below 100 KHz may be neglected and impedances in these frequency regions are unimportant.

The Impedance of a Stub

A trade-off between noise introduced by pulse reflections or ringing and adequate power for detection is effected by varying the impedance that a given stub will present to the multiplex bus. A short computer program was written to calculate the impedance that a stub presents to the main bus and the results of those calculations are shown in Figures 5 and 6. Both show a family of curves of the stub impedance seen from the bus as a function of the receiver resistance in ohms and the length of the stub. Figure 5 was drawn for a stub using a 71 ohm characteristic impedance cable with a 2.5:1 transformer at the stub-to-bus junction and a 1:1.85 transformer at the receiver. The family of solid lines indicates the impedance as a function of stub lengths from 1 to 30 feet and the dotted lines show the phase angle of the impedance. Note that the impedance seen by the bus is the same for all lengths of stub for a receiver resistance of 100 to 500 ohms. The stub impedance varies greatly as a function of stub length when the receiver resistance exceeds a thousand ohms. Thus, the receiver resistance should be maintained at 1,000 ohms or less for these cases if the stub is to present essentially the same impedance regardless of length.

The significance of the phase angle of the stub impedance should not be overlooked. Power can be considered as a dot product of two vector quantities, voltage and current.

(1) $$P = \vec{E}\cdot\vec{I} = EI \cos \theta_z = \frac{E^2}{Z} \cos \theta_z$$

where

$\vec{E}$ is the sinusoidal voltage
$\vec{I}$ is the sinusoidal current
Z is the magnitude of the impedance
θ_z is the angle between current and voltage

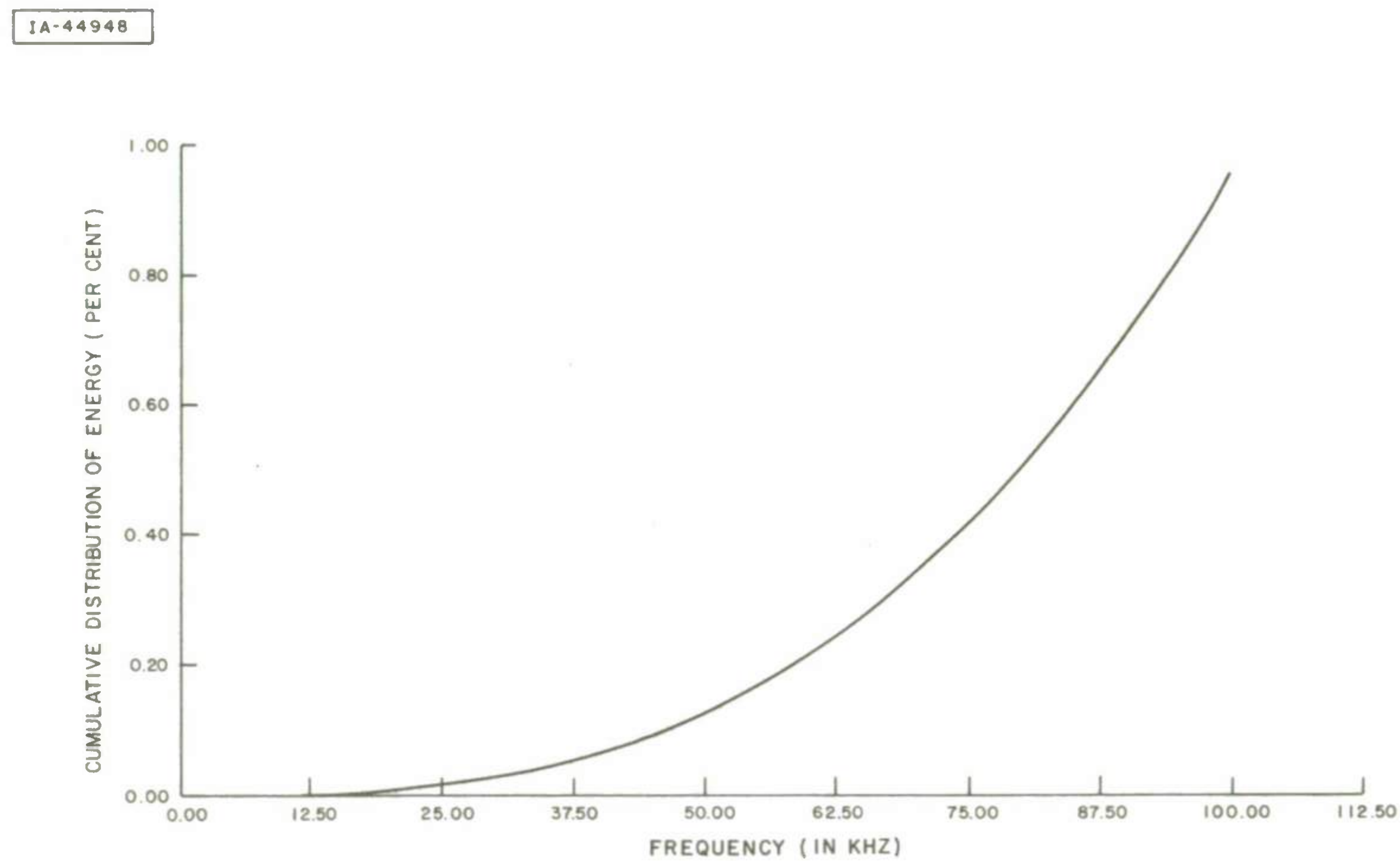

Figure 4 CUMULATIVE ENERGY DISTRIBUTION FOR THE SPECTRUM OF AN AVERAGE DATA WORD

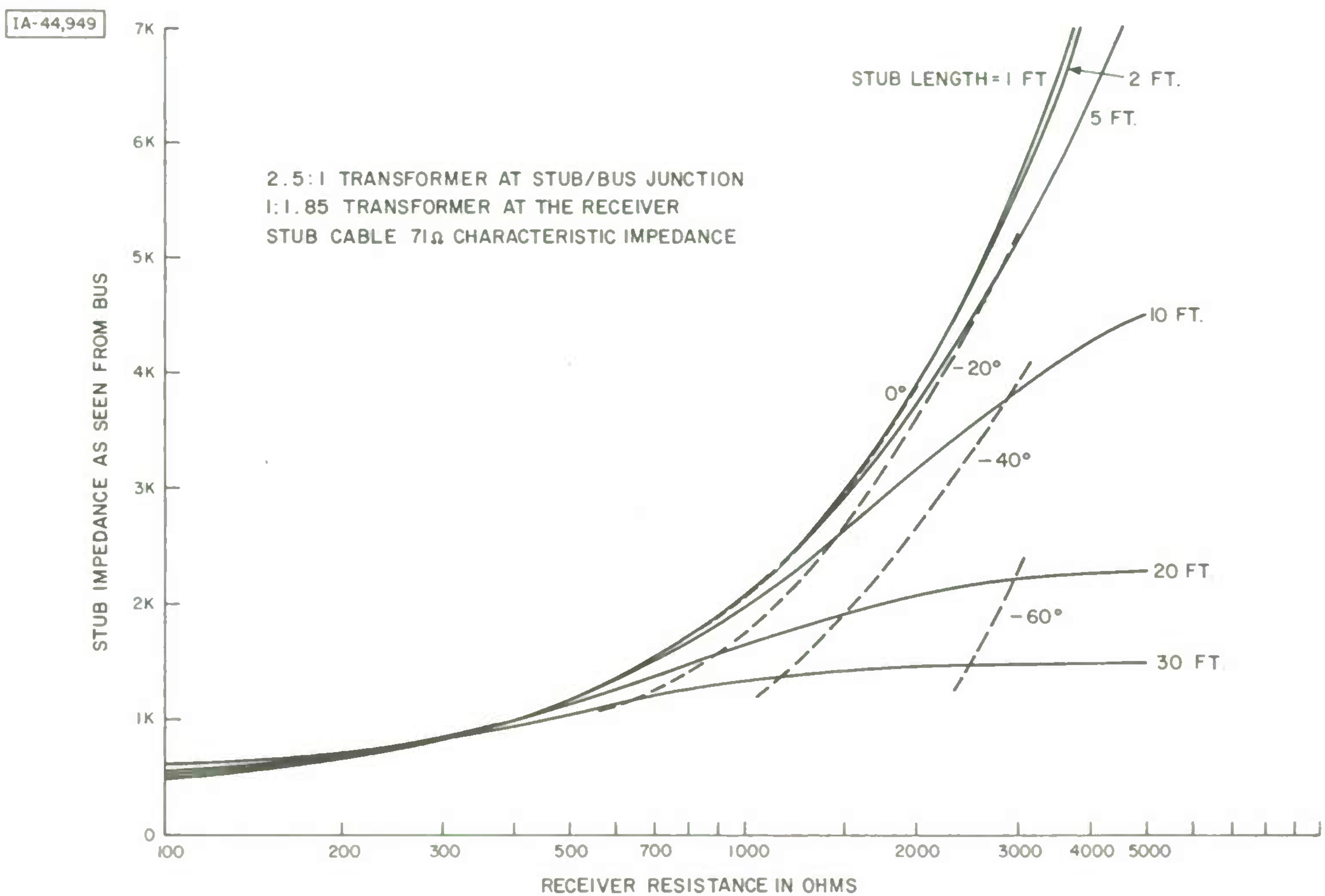

Figure 5 STUB IMPEDANCE VERSUS RECEIVER RESISTANCE (WITH STUB/BUS COUPLING TRANSFORMER)

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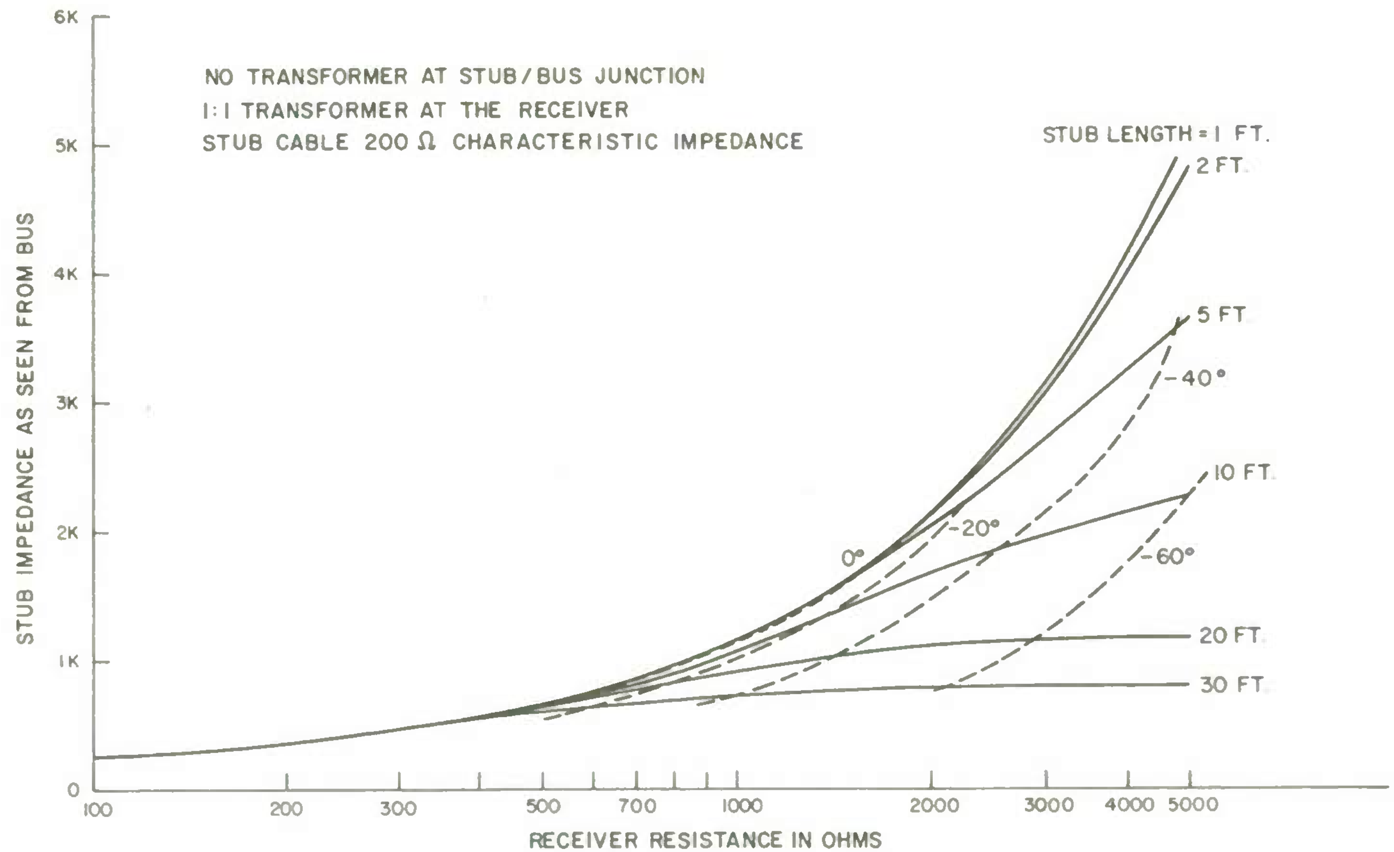


Figure 6 STUB IMPEDANCE VERSUS RECEIVER RESISTANCE (NO STUB/BUS COUPLING TRANSFORMER)

Let us assume that the voltage and the current are those of the stub at the stub-to-bus junction. When we replace current, I, by voltage divided by impedance, E/Z, in the equation, it becomes clear that the power is inversely proportional to the magnitude of the impedance and directly proportional to the cosine of the impedance angle. As a first approximation, the voltage at the main bus will be relatively unaffected as the stub impedance varies as long as the impedance of the stub is high by comparison with the bus impedance. Consequently, the power which enters the stub is approximately inversely proportional to the impedance and directly proportional to the cosine of the impedance angle. As the impedance angle varies from 0 degrees to 60 degrees, the cosine is reduced from 1 to 0.5. At 70 degrees it is approximately a third, and at 80 degrees about a sixth. Thus, a change in phase angle for values greater than 30 degrees is reflected by a significant change in the real power absorbed by a stub. It can be seen from Figures 4 and 5 that angles larger than 60 degrees do not occur until the receiver resistance exceeds 2,000 ohms as long as the stub length remains between 1 and 30 feet.

Figures 5 and 6 also show that the impedance which the stub presents to the bus remains reasonably high when the stub is lengthened to 30 feet. In fact, for a receiver resistance of a thousand ohms the total variation in stub impedance is only between 1300 and 2050 ohms for the transformer coupled stub, and between 720 and 1150 ohms for the stub with the 200 ohm characteristic impedance cable as long as the stub length remains between 1 and 30 feet. This stub impedance is in an acceptable region, and the variation with stub length can probably be tolerated.

Signal Waveforms

The computer simulation transforms the input waveform into a Fourier series of sine waves. The impedances and the voltages are then computed throughout the network at each of the frequencies which resulted from the Fourier analysis. Finally, the component sine waves can be recombined at any desired point in the network to provide the amplitude of the composite signal which can then be plotted on the Calcomp plotter.

Simulations were run using a trapezoidal input waveform with a rise time of 40 nanoseconds. This rise time was chosen to agree with that of the laboratory signal generator for convenience in correlating simulation results with laboratory measurements. Under these conditions the simulation program was run for each of the cases detailed in Table II. One set of runs was made with the

transmitter in stub 1 at the extreme end of the bus. The other set of runs was made with the transmitter in stub 14 near the center of the bus. In each case the stubs were randomly spaced along a bus of 250 foot length. The same stub spacings and lengths were retained throughout all the simulations.

Figure 7 shows the waveforms at the transmitter and receivers when the transmitter is in stub number 1. The transmitter voltage departs from the ideal waveform discussed above because the transmitter internal impedance was included in the model. In this way, the effect of the driving point impedance at the transmitter end of the stub on a real generator which has its own internal impedance can be assessed.

The top horizontal line of Figure 7 represents the waveforms starting with stub 1 through stub 32 for Case 3 of Table III. This case uses a 200 ohm characteristic impedance cable for the stub with no transformer at the stub-to-bus junction. The waveforms at stubs adjacent to the transmitter show relatively little distortion. As the signal travels away from the transmitter along the bus, the transit time delay is shown in the successively increasing lag of the waveform. There is also some rounding of corners which increases at points successively removed from the transmitter. In all, however, these waveforms are excellent--relatively undistorted and easy to detect using a simple threshold detector without additional filtering.

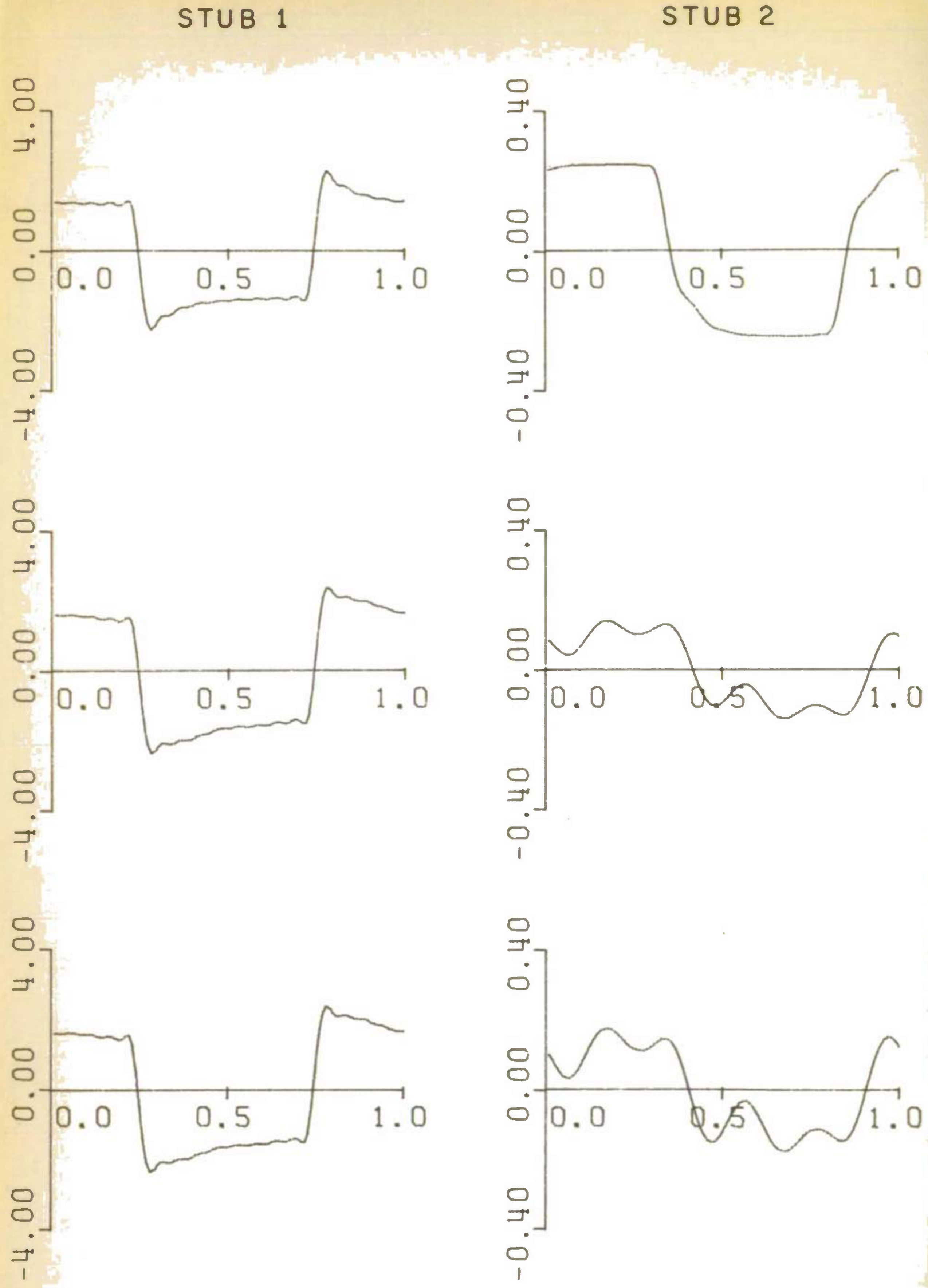
The second row of waveforms shown in Figure 7 represents Case 2 of Table II--71 ohm cable with a coupling transformer at the stub-to-bus junction and a 1,000 ohm receiver resistance. Note that the transmitter waveform in stub 1 is nearly identical to that of the previous case. The higher frequency distortion which appears on the signal at the receivers in the vicinity of the transmitter apparently arises largely as a result of the stub-to-bus junction coupling transformer parameters, though reflections probably also play a part. In stubs adjacent to the transmitter the effect is so severe that a simple threshold detector can not be used without low pass filtering. The high frequency components are rapidly lost as the waveforms proceed towards the end of the bus away from the transmitter. The bus tends to have a low pass filter effect, ultimately reducing the waveform to a sine wave. The waveforms are generally acceptable if a low pass filter is included in the receiver.

The last row of Figure 7 illustrates the waveforms which correspond to Case 1 of Table II. The parameters are the same as

RECEIVER RESISTANCE 1000 Ω
RECEIVER TRANSFORMER TURNS RATIO 1:1
STUB CABLE : 200 OHM CHARACTERISTIC IMPEDANCE
(CASE 3 OF TABLE II)

RECEIVER RESISTANCE 1000 Ω
RECEIVER TRANSFORMER TURNS RATIO 1.85 : 1
STUB-TO-BUS TRANSFORMER TURNS RATIO 2.5:1
(CASE 2 OF TABLE II)

RECEIVER RESISTANCE 3730 Ω
RECEIVER TRANSFORMER TURNS RATIO 1.85 : 1
STUB-TO-BUS TRANSFORMER TURNS RATIO 2.5:1
(CASE 1 OF TABLE II)



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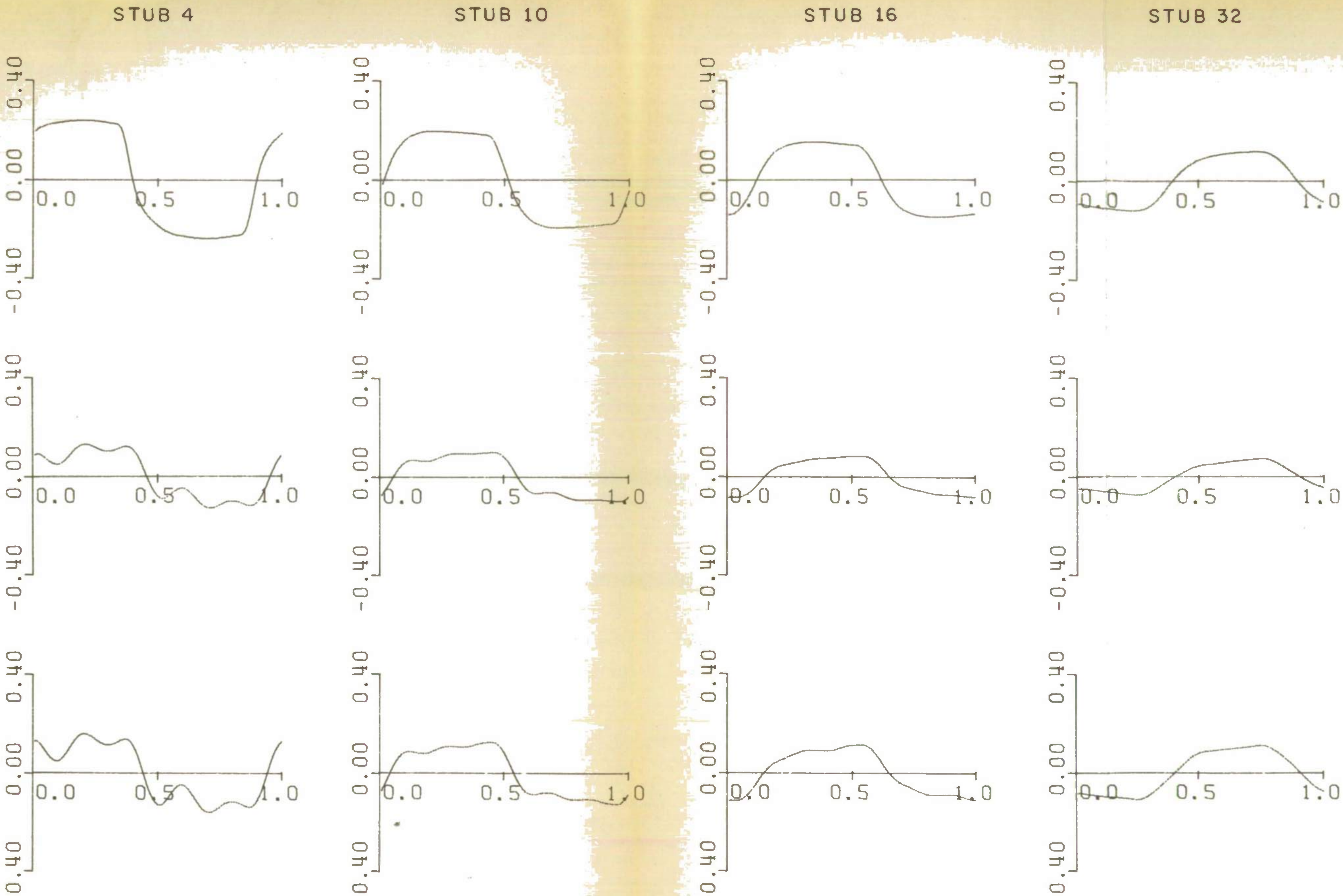


Figure 7 BUS WAVEFORMS WITH TRANSMITTER IN STUB 1

the immediately preceding case except that the receiver resistance has been changed to 3730 ohms. The waveforms are almost identical to those of the preceding case except that there is some worsening of the high frequency distortion in stubs adjacent to the transmitter.

Both cases which use stub-to-bus coupling transformers produce waveforms which are inferior to those of the 200 ohm characteristic impedance cable. On the basis of the simulations to date, the reason for the distortion appears to be the ringing of the coupling transformer with added distortion created by reflections. However, additional analysis and simulation will be required to determine the cause of the distortion with certainty.

Figure 8 shows the waveforms for the same cases with the transmitter moved to stub 14. Essentially the same remarks also apply to Figure 8. Again the 200 ohm characteristic impedance cable without a stub-to-bus junction transformer produces waveforms which are superior.

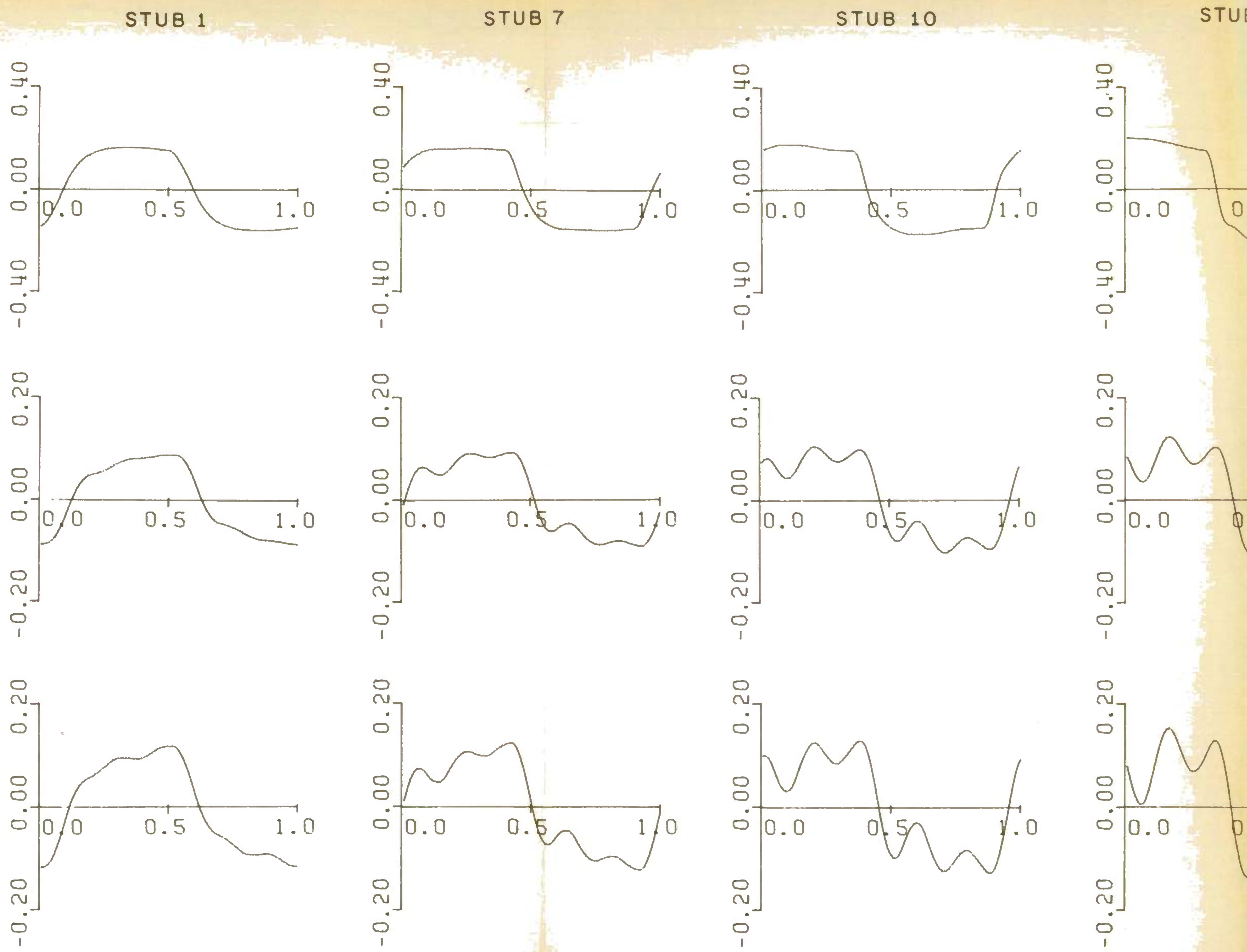
Transmitter to Receiver Power Losses

The simulation program defines not only the waveforms at various points throughout the network but the impedances at each frequency at these points. Thus, it is possible to calculate the power at each harmonic as well as the total power. This is done in terms of the power loss between transmitter and receiver, and is provided as a part of the normal printout. Figure 9 shows a graph of transmitter to receiver power losses as a function of the receiver stub for each of the three cases of Table II. The transmitter is located in stub 1 for all cases and the power calculation is based upon the total power, i.e., all harmonics. Losses are least in the stubs immediately adjacent to the transmitter, as might be expected, and greatest in those stubs most distant from the transmitter. The greatest losses occur for Case 1 which has a stub-to-bus junction transformer, 71 ohm cable, and a 3730 ohm receiver load. When the receiver load resistance is decreased to a thousand ohms (Case 2) the transmitter to receiver losses actually decrease by 2.5 to 4 dB. From Figure 5 we note that the stub impedances corresponding to these cases are slightly over 2100 ohms and about 1600 ohms respectively. Therefore, a decrease in the impedance which the stub presents to the bus results in a smaller transmitter to receiver loss. The reasons for this were treated in some detail in Reference 3. Finally, the minimum transmitter to receiver loss occurs for the stub with the 200 ohm characteristic impedance cable (Case 3) where an additional 2.5 to 4 dB is gained. Appendix I shows the detailed

RECEIVER RESISTANCE 1000 Ω
RECEIVER TRANSFORMER TURNS RATIO 1:1
STUB CABLE : 200 OHM CHARACTERISTIC IMPEDANCE
(CASE 3 OF TABLE II)

RECEIVER RESISTANCE 1000 Ω
RECEIVER TRANSFORMER TURNS RATIO 1.85 : 1
STUB-TO-BUS TRANSFORMER TURNS RATIO 2.5:1
(CASE 2 OF TABLE II)

RECEIVER RESISTANCE 3730 Ω
RECEIVER TRANSFORMER TURNS RATIO 1.85:1
STUB-TO-BUS TRANSFORMER TURNS RATIO 2.5:1
(CASE 1 OF TABLE II)



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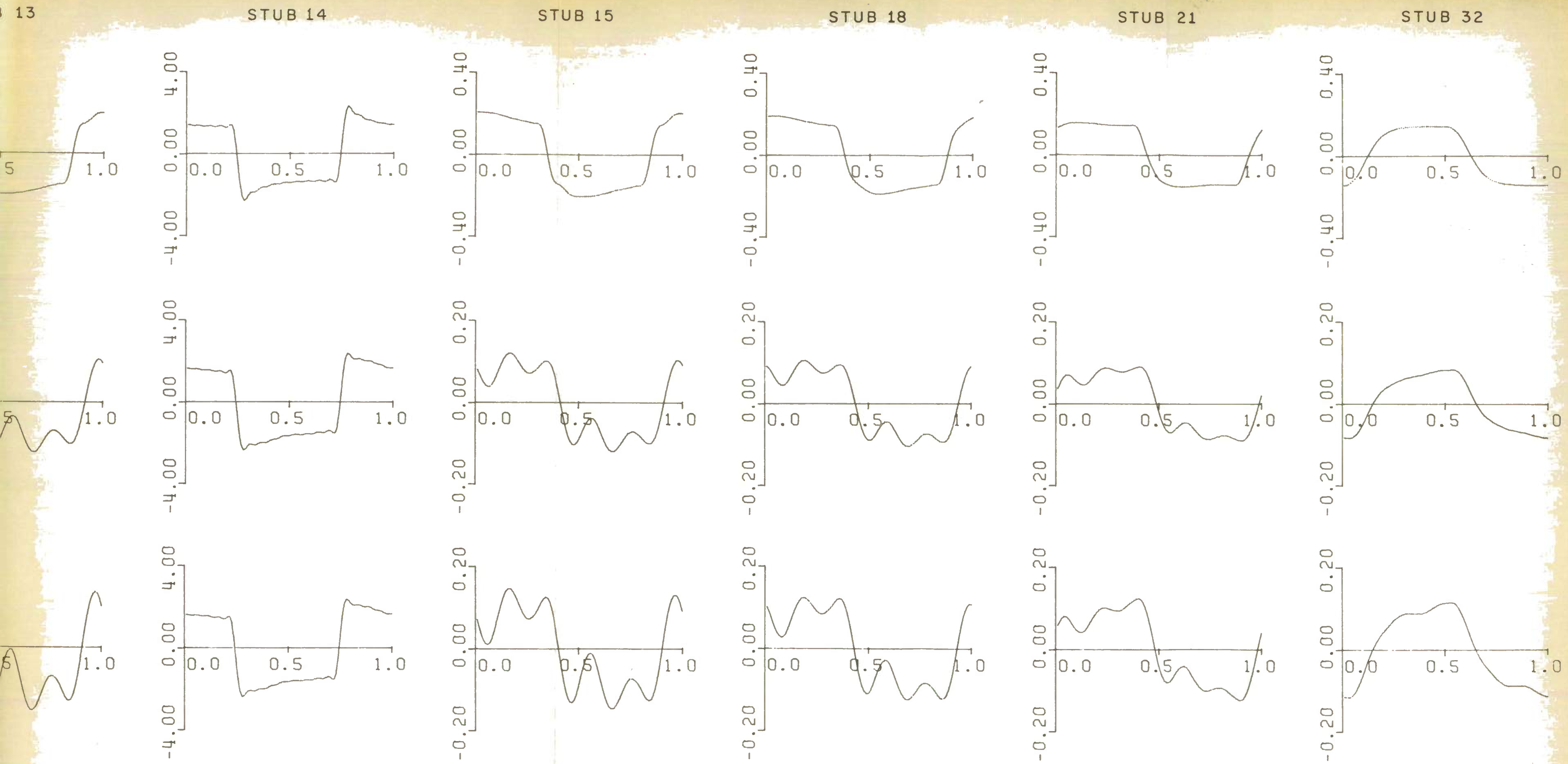

Figure 8 BUS WAVEFORMS WITH TRANSMITTER IN STUB 14

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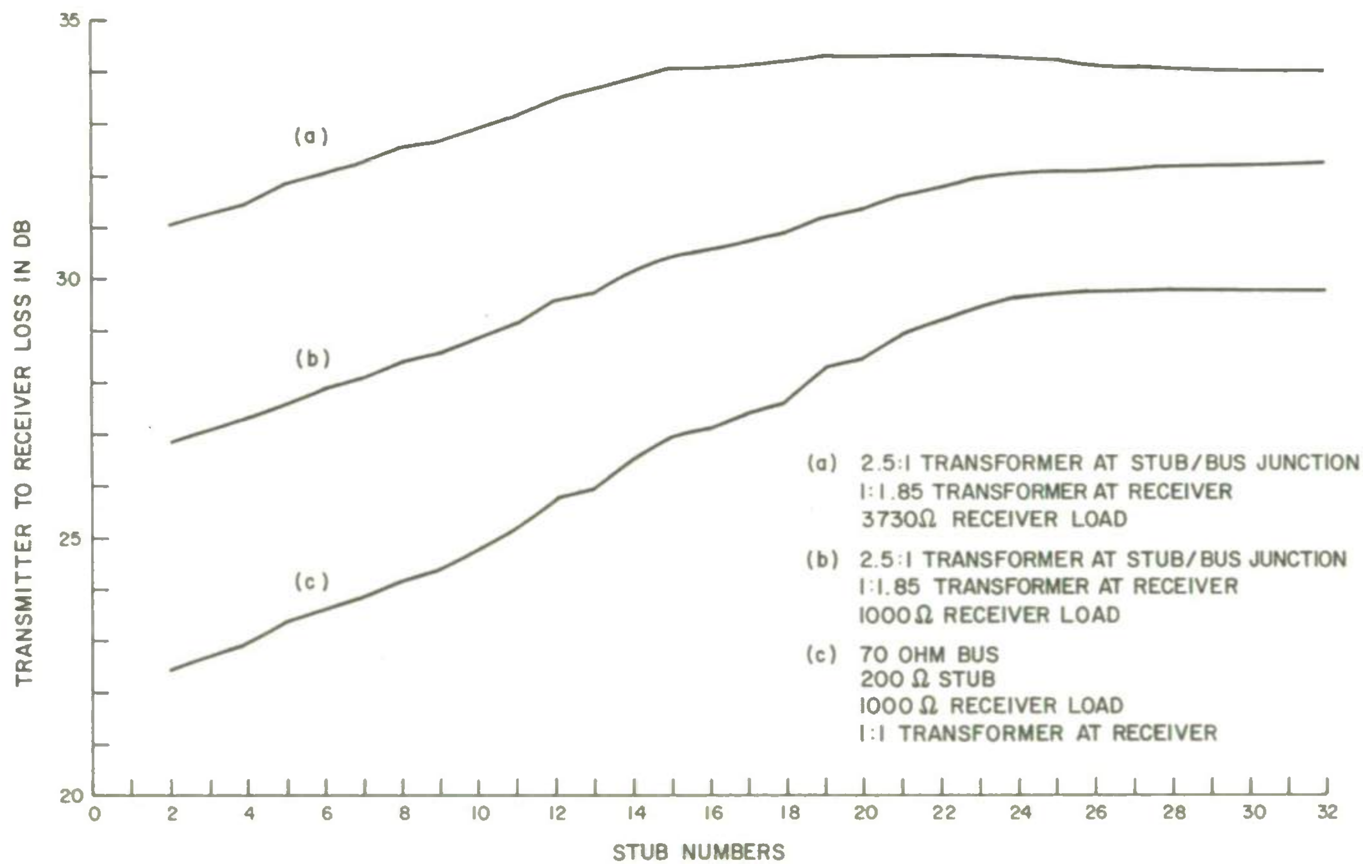

Figure 9 TRANSMITTER TO RECEIVER LOSS AS A FUNCTION OF STUB POSITION (TRANSMITTER IN STUB 1)

printout for each of these cases. The column labeled "combined" indicates the total power loss between transmitter and receiver. Successive columns show the losses at each harmonic, beginning with the fundamental or first harmonic which is 1 MHz. This printout corroborates the additional losses at the higher frequencies.

Figure 10 shows the power losses for the same cases when the transmitter is moved to stub 14. The same remarks are still applicable except that the improvement in power transfer is even greater for the 200 ohm characteristic impedance cable.

Appendix II presents the tabulated power loss from transmitter to receiver for those cases in which the transmitter is in stub 14.

Summary

The preceding tables and figures have shown clearly that Case 3 of Table II, which has stubs of 200 ohm characteristic impedance cable, is superior to Cases 1 and 2 of Table II for the following reasons:

1. The waveforms are better as shown in Figures 7 and 8.

2. The transmitter to receiver loss is less as shown in Figures 9 and 10 and Tables III and IV.

Besides improved waveform and power, Case 3 has the advantage of not requiring the additional transformer required for Cases Number 1 and 2. This transformer represents an additional part which might fail and an additional potential source of noise to the system (the transformer can act like an antenna for ambient electrical noise.)

Although the results presented for stubs of 200 ohm characteristic impedance cable represent simulations without laboratory verification, previous experience with the simulation on other cases has shown it to be dependable and accurate. Measurements will be made using stubs of 200 ohm characteristic impedance cable. Meantime, MIL-STD-1553 (USAF) is undergoing revision and a new Tri-Service Standard is being developed. It will probably not be possible to verify the results presented in this report in the laboratory before these documents are issued. However, it seems imperative that the information contained in this report be taken into consideration and both standards revised so that they do not preclude the use of stubs with the high characteristic impedance cable with its potential advantages.

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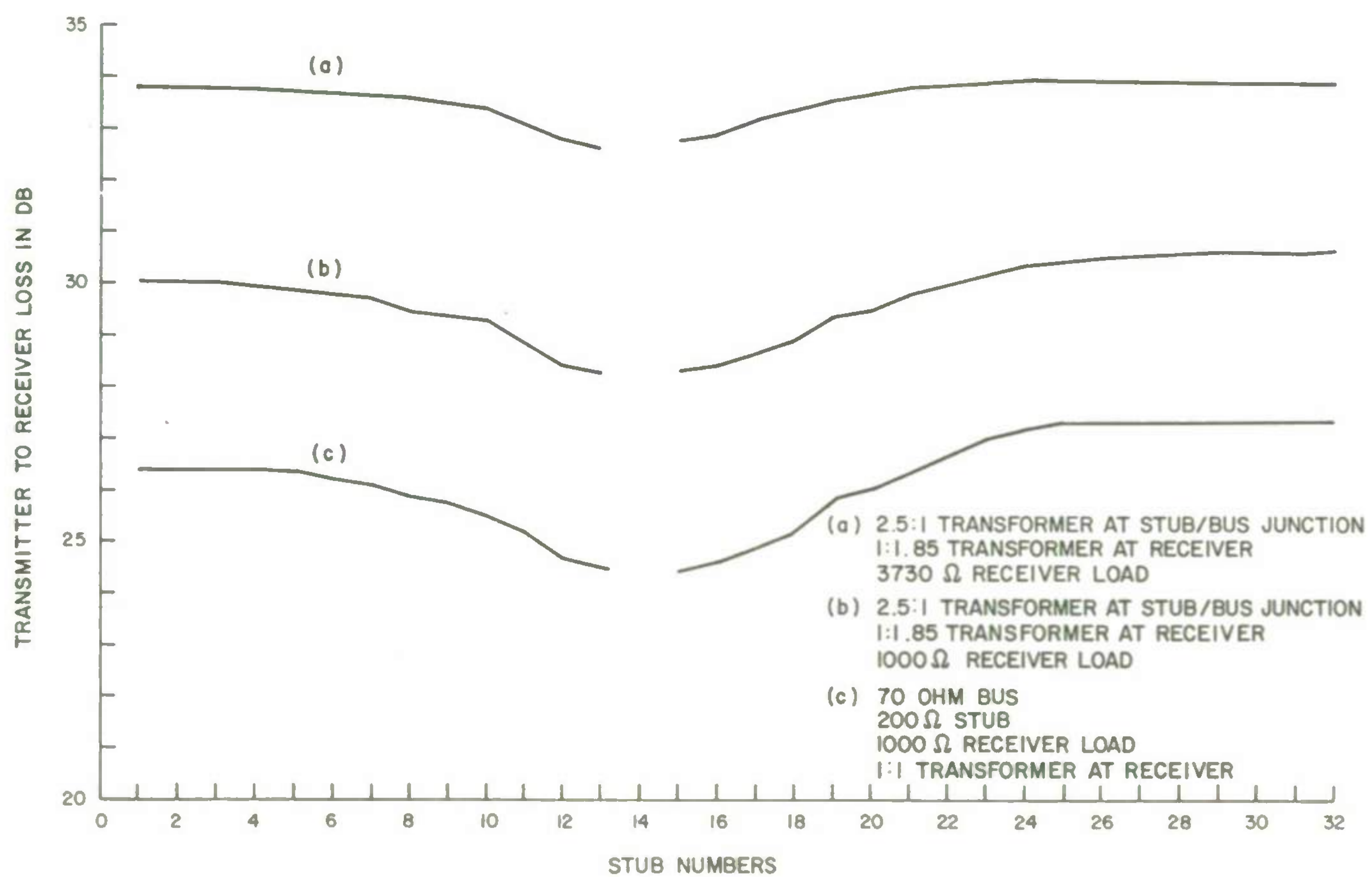

Figure 10 TRANSMITTER TO RECEIVER LOSS AS A FUNCTION OF STUB POSITION (TRANSMITTER IN STUB 14)

The simulation program which was used to produce the data on which this report is based is an extremely flexible tool. It can provide guidance toward establishing multiplex bus parameters more quickly and inexpensively than laboratory work. Naturally, any final results should be verified in the laboratory. But questions like, "What tolerances should be assigned to the cable parameters?" and "What effect do cable parameter changes have on the waveforms?" can only be answered effectively by means of a simulation. The MITRE simulation or its equivalent should be used to determine optimum receiver resistance for all line lengths in terms of transmitter to receiver losses and waveforms. The simulation should also be used to determine the design constraints which result from choices of transformer parameters, stub placement, line length, and other factors. In this way the constraints inherent in the transmission medium and the configuration of a multiplex bus can be understood before costly errors are incorporated in operational systems.

APPENDIX I

COMPUTER PRINTOUT OF TRANSMITTER TO RECEIVER LOSSES, TRANSMITTER IN STUB 1

Case I. Transmitter in Stub 1

POWER RATIO AT RECEIVERS (DB)

RECEIVER	COMBINED	** HARMONIC ** 1	3	5	7	9	11	13	15	17
2	-31.02	-31.81	-25.93	-23.97	-34.47	-41.52	-45.45	-45.30	-41.33	-30.26
3	-31.27	-31.90	-27.43	-25.11	-34.73	-41.32	-44.17	-44.83	-41.07	-30.17
4	-31.49	-32.00	-28.09	-25.78	-34.80	-40.97	-45.79	-45.28	-41.32	-30.13
5	-31.85	-32.19	-29.00	-27.59	-35.17	-42.36	-44.40	-44.98	-41.38	-30.47
6	-32.05	-32.31	-29.31	-28.91	-35.39	-42.35	-44.83	-45.16	-41.21	-30.33
7	-32.25	-32.46	-29.42	-30.14	-35.33	-41.23	-45.95	-45.40	-41.26	-30.70
8	-32.53	-32.70	-29.31	-32.16	-35.57	-41.55	-44.54	-45.19	-41.33	-30.63
9	-32.67	-32.83	-29.23	-33.09	-35.92	-42.38	-44.78	-45.39	-41.16	-30.90
10	-32.89	-33.04	-29.31	-34.05	-35.21	-42.45	-46.04	-45.32	-41.65	-30.65
11	-33.15	-33.27	-29.70	-34.95	-36.52	-41.44	-45.13	-45.43	-41.23	-30.98
12	-33.49	-33.55	-30.54	-35.62	-36.92	-43.06	-45.65	-45.48	-41.66	-31.11
13	-33.59	-33.64	-30.90	-37.24	-35.87	-43.42	-46.16	-45.32	-41.26	-31.19
14	-33.37	-33.35	-31.90	-39.39	-36.84	-41.99	-45.14	-45.76	-41.95	-31.11
15	-34.03	-34.00	-32.27	-41.59	-37.25	-42.05	-45.53	-45.45	-41.22	-31.32
16	-34.07	-34.03	-32.32	-42.29	-37.43	-42.52	-45.83	-45.28	-41.20	-31.25
17	-34.15	-34.11	-32.42	-43.45	-37.49	-43.11	-46.04	-45.35	-41.85	-31.52
18	-34.22	-34.17	-32.47	-44.29	-37.56	-43.49	-45.65	-45.87	-41.90	-31.61
19	-34.30	-34.25	-32.43	-45.35	-38.56	-42.83	-45.99	-45.52	-41.82	-31.59
20	-34.32	-34.27	-32.40	-46.95	-38.94	-42.63	-46.28	-45.42	-42.04	-31.82
21	-34.33	-34.29	-32.58	-48.13	-39.05	-43.15	-45.74	-46.12	-41.49	-31.61
22	-34.32	-34.25	-32.92	-49.14	-38.73	-43.92	-45.78	-45.68	-42.10	-32.05
23	-34.29	-34.19	-33.59	-50.73	-38.72	-43.40	-46.47	-45.86	-41.56	-31.75
24	-34.25	-34.13	-34.25	-52.41	-39.31	-42.92	-45.99	-46.18	-42.07	-32.29
25	-34.22	-34.07	-34.60	-53.53	-39.35	-43.20	-45.70	-45.60	-41.95	-32.03
26	-34.17	-34.01	-35.35	-55.50	-40.22	-43.93	-46.22	-45.79	-41.66	-32.20
27	-34.15	-33.99	-35.54	-56.05	-40.19	-44.15	-45.45	-46.06	-41.82	-32.49
28	-34.13	-33.96	-35.91	-57.02	-39.96	-44.04	-45.51	-46.27	-42.17	-32.50
29	-34.08	-33.90	-36.09	-59.37	-40.15	-43.77	-45.26	-45.94	-41.87	-32.54
30	-34.05	-33.93	-35.83	-61.57	-40.94	-43.98	-46.45	-46.18	-42.10	-32.67
31	-34.05	-33.88	-35.74	-62.10	-41.07	-44.06	-46.46	-46.19	-42.14	-32.57
32	-34.06	-33.90	-35.51	-63.46	-41.33	-44.46	-46.64	-46.23	-42.13	-32.77

POWER RATIO=(RECEIVER POWER/XMTR OUTPUT POWER) IN DB.

Case 2, Transmitter in Stub 1

POWER RATIO AT RECEIVERS (DB)

RECEIVER	COMBINED	** HARMONIC ** 1	3	5	7	9	11	13	15	17
2	-26.93	-27.25	-24.30	-21.51	-31.39	-40.32	-45.18	-46.14	-43.16	-33.47
3	-27.08	-27.41	-24.87	-22.57	-31.59	-40.24	-43.91	-45.62	-42.87	-33.42
4	-27.30	-27.56	-25.46	-23.37	-31.30	-39.45	-45.57	-46.11	-43.13	-33.41
5	-27.64	-27.80	-26.18	-24.98	-32.28	-40.91	-44.13	-45.78	-43.21	-33.60
6	-27.84	-27.97	-26.40	-25.89	-32.55	-40.31	-44.59	-45.98	-42.99	-33.52
7	-28.05	-28.14	-26.51	-26.97	-32.56	-39.70	-45.73	-46.22	-43.06	-33.73
8	-28.37	-28.43	-26.54	-29.82	-32.92	-40.43	-44.38	-46.00	-43.11	-33.69
9	-28.55	-28.60	-26.57	-29.63	-33.24	-41.45	-44.54	-46.21	-42.94	-33.85
10	-28.81	-28.85	-26.73	-30.52	-33.62	-40.96	-45.82	-46.13	-43.47	-33.70
11	-29.13	-29.15	-27.24	-31.38	-34.02	-39.97	-44.88	-46.25	-43.00	-33.91
12	-29.56	-29.55	-28.10	-32.75	-34.43	-41.59	-45.43	-46.29	-43.46	-33.97
13	-29.72	-29.69	-28.44	-33.27	-34.33	-42.02	-45.95	-46.13	-43.02	-34.02
14	-30.14	-30.08	-29.32	-35.25	-34.44	-40.53	-44.90	-46.59	-43.78	-33.98
15	-30.44	-30.36	-29.68	-37.17	-35.08	-40.63	-45.32	-46.26	-42.97	-34.09
16	-30.52	-30.44	-29.73	-37.55	-35.22	-40.95	-45.63	-46.07	-42.94	-34.05
17	-30.72	-30.64	-29.85	-38.62	-35.35	-41.77	-45.33	-46.16	-43.64	-34.19
18	-30.88	-30.81	-29.92	-39.35	-35.47	-42.14	-45.42	-46.70	-43.70	-34.26
19	-31.24	-31.17	-30.03	-41.23	-36.56	-41.44	-45.30	-46.33	-43.60	-34.25
20	-31.35	-31.28	-30.07	-41.74	-36.95	-41.76	-46.08	-46.23	-43.84	-34.38
21	-31.59	-31.52	-30.35	-42.76	-37.11	-41.84	-45.52	-46.95	-43.23	-34.26
22	-31.76	-31.67	-30.73	-43.66	-35.96	-42.52	-45.58	-46.49	-43.90	-34.51
23	-31.92	-31.82	-31.40	-45.11	-36.95	-42.07	-46.29	-46.68	-43.30	-34.35
24	-32.03	-31.90	-32.03	-46.55	-37.60	-41.60	-45.78	-47.01	-43.85	-34.64
25	-32.09	-31.95	-32.52	-47.73	-38.19	-41.91	-45.49	-46.41	-43.72	-34.50
26	-32.13	-31.98	-33.04	-49.02	-38.62	-42.72	-46.03	-46.60	-43.39	-34.64
27	-32.15	-31.99	-33.22	-49.44	-38.61	-42.91	-46.27	-46.89	-43.56	-34.75
28	-32.17	-32.01	-33.57	-50.29	-38.37	-42.79	-45.33	-47.11	-43.94	-34.75
29	-32.21	-32.03	-33.95	-52.90	-38.73	-42.47	-46.08	-46.76	-43.61	-34.79
30	-32.21	-32.04	-33.90	-54.26	-39.57	-42.75	-46.27	-47.01	-43.85	-34.85
31	-32.22	-32.04	-33.87	-54.56	-39.32	-42.34	-46.28	-47.02	-43.90	-34.30
32	-32.25	-32.08	-33.80	-55.56	-40.65	-43.27	-45.48	-47.06	-43.87	-34.91

POWER RATIO=(RECEIVER POWER/XMTR OUTPUT POWER) IN DB.

Case 3, Transmitter in Stub 1

POWER RATIO AT RECEIVERS (DB)

		** HARMONIC **								
	COMBINED	1	3	5	7	9	11	13	15	17
RECEIVER										
2	-22.43	-22.47	-21.94	-21.38	-21.37	-20.50	-20.37	-22.94	-25.46	-27.66
3	-22.71	-22.72	-22.47	-22.53	-22.60	-23.72	-24.09	-23.59	-24.53	-26.00
4	-22.96	-22.95	-23.15	-23.17	-23.32	-24.45	-25.78	-26.39	-26.78	-26.59
5	-23.33	-23.28	-24.14	-24.13	-25.79	-27.71	-27.64	-26.18	-25.70	-28.50
6	-23.56	-23.47	-24.54	-24.52	-26.44	-29.98	-30.83	-28.29	-27.46	-25.41
7	-23.80	-23.73	-24.79	-25.37	-27.39	-30.74	-32.06	-29.87	-28.26	-29.16
8	-24.17	-24.11	-24.88	-26.63	-29.97	-34.07	-34.76	-30.37	-28.79	-26.27
9	-24.39	-24.33	-24.88	-27.03	-30.51	-35.94	-36.90	-31.57	-29.57	-29.31
10	-24.73	-24.67	-25.06	-27.57	-31.26	-37.67	-39.80	-34.70	-28.32	-26.71
11	-25.14	-25.09	-25.52	-25.10	-33.00	-33.31	-40.47	-35.06	-31.74	-30.22
12	-25.72	-25.65	-26.43	-23.75	-34.71	-43.34	-45.16	-37.22	-30.53	-28.16
13	-25.93	-25.86	-26.82	-29.10	-34.50	-43.42	-45.93	-39.11	-31.65	-30.04
14	-26.52	-26.47	-27.95	-30.37	-35.95	-45.32	-46.92	-38.31	-32.44	-28.42
15	-26.95	-26.95	-28.42	-31.72	-39.31	-49.59	-51.21	-40.71	-32.27	-29.96
16	-27.09	-26.99	-28.50	-31.35	-40.15	-50.60	-52.68	-42.05	-32.81	-28.85
17	-27.41	-27.31	-28.71	-32.39	-40.65	-52.33	-55.49	-45.10	-34.65	-28.50
18	-27.63	-27.59	-23.85	-32.02	-41.03	-52.33	-56.04	-45.37	-35.33	-31.31
19	-28.29	-29.21	-29.02	-34.17	-43.54	-55.56	-59.65	-47.11	-36.10	-29.33
20	-28.49	-28.42	-29.05	-34.20	-44.20	-57.49	-60.76	-48.06	-35.71	-30.90
21	-28.91	-29.94	-29.33	-34.58	-45.95	-60.12	-63.47	-49.40	-37.32	-30.15
22	-29.20	-29.12	-29.73	-35.27	-46.46	-61.36	-65.53	-50.76	-37.48	-31.24
23	-29.48	-29.39	-30.47	-36.74	-47.52	-63.34	-67.73	-52.74	-37.78	-30.68
24	-29.63	-29.51	-31.19	-37.77	-49.49	-65.77	-69.65	-53.04	-39.68	-31.56
25	-29.70	-29.57	-31.30	-38.15	-51.57	-68.30	-71.97	-53.92	-37.71	-32.34
26	-29.75	-29.60	-32.46	-33.32	-52.78	-72.04	-76.66	-58.01	-39.39	-30.76
27	-29.76	-29.60	-32.70	-33.45	-52.69	-72.44	-77.82	-59.67	-41.14	-31.23
28	-29.78	-29.61	-33.13	-39.20	-53.00	-72.72	-78.20	-59.96	-42.95	-33.32
29	-29.77	-29.60	-33.63	-41.55	-56.13	-75.46	-81.22	-60.66	-41.33	-31.90
30	-29.75	-29.53	-33.46	-41.96	-57.43	-78.30	-84.33	-63.32	-43.54	-33.35
31	-29.75	-29.57	-33.33	-41.99	-57.84	-79.34	-84.95	-63.65	-43.67	-33.66
32	-29.76	-29.59	-33.18	-41.94	-53.85	-82.27	-83.58	-66.10	-44.42	-33.57

POWER RATIO=(RECEIVER POWER/XMTR OUTPUT POWER) IN DB.

APPENDIX II

COMPUTER PRINTOUT OF TRANSMITTER TO
RECEIVER LOSSES, TRANSMITTER IN STUB 14

Case 1. Transmitter in Stub 14

POWER RATIO AT RECEIVERS (DB)

RECEIVER	COMBINED	1	3	5	7	9	11	13	15	17
		** HARMONIC **								
1	-33.78	-33.76	-31.87	-39.20	-36.90	-42.03	-45.17	-45.75	-41.93	-31.11
2	-33.77	-33.75	-32.05	-38.40	-36.23	-41.64	-44.88	-45.55	-41.92	-31.00
3	-33.76	-33.76	-32.34	-36.04	-35.53	-41.57	-45.12	-45.82	-41.95	-30.93
4	-33.74	-33.75	-32.22	-34.28	-35.70	-41.92	-44.99	-45.45	-41.73	-30.70
5	-33.70	-33.82	-31.39	-32.73	-36.11	-41.36	-44.90	-45.62	-41.82	-30.73
6	-33.68	-33.86	-30.80	-32.13	-35.61	-41.22	-44.99	-45.30	-41.61	-30.59
7	-33.64	-33.90	-30.36	-31.23	-34.71	-41.29	-44.51	-45.36	-41.83	-30.55
8	-33.55	-33.95	-29.93	-29.52	-34.30	-41.34	-44.87	-45.54	-41.60	-30.40
9	-33.49	-33.97	-29.85	-28.54	-34.55	-41.11	-44.37	-45.04	-41.69	-30.46
10	-33.34	-33.99	-29.35	-26.96	-34.72	-40.72	-44.23	-45.49	-41.55	-30.14
11	-33.10	-33.98	-29.50	-25.37	-34.31	-40.96	-44.64	-45.29	-41.63	-30.21
12	-32.76	-33.94	-29.39	-23.90	-33.69	-41.05	-44.48	-45.43	-41.53	-30.14
13	-32.63	-33.91	-29.21	-23.43	-33.55	-40.72	-44.08	-45.55	-41.48	-30.15
15	-32.73	-33.95	-29.04	-24.06	-33.79	-40.29	-44.90	-44.63	-40.82	-30.06
16	-32.93	-33.99	-29.08	-24.67	-33.89	-40.58	-45.20	-44.45	-40.80	-30.00
17	-33.20	-34.07	-29.19	-25.34	-33.95	-41.36	-45.40	-44.53	-41.45	-30.26
18	-33.37	-34.13	-29.24	-26.67	-34.02	-41.75	-45.01	-45.04	-41.50	-30.36
19	-33.66	-34.22	-29.19	-27.72	-35.02	-41.09	-45.36	-44.70	-41.42	-30.34
20	-33.72	-34.23	-29.17	-29.34	-35.40	-40.89	-45.64	-44.60	-41.64	-30.56
21	-33.82	-34.24	-29.25	-30.51	-35.51	-41.41	-45.10	-45.30	-41.09	-30.35
22	-33.88	-34.21	-29.69	-31.52	-35.19	-42.19	-45.15	-44.86	-41.70	-30.60
23	-33.94	-34.15	-30.36	-33.12	-35.19	-41.57	-45.84	-45.02	-41.16	-30.49
24	-33.97	-34.05	-31.02	-34.79	-35.77	-41.19	-45.35	-45.36	-41.67	-31.03
25	-33.98	-34.03	-31.55	-35.21	-36.21	-41.46	-45.07	-44.78	-41.55	-30.77
26	-33.97	-33.97	-32.12	-37.25	-36.68	-42.24	-45.58	-44.96	-41.26	-31.01
27	-33.97	-33.95	-32.31	-38.42	-35.65	-42.42	-45.81	-45.24	-41.42	-31.23
28	-33.96	-33.91	-32.54	-39.41	-36.36	-42.31	-45.88	-45.45	-41.77	-31.24
29	-33.93	-33.86	-32.85	-42.26	-36.61	-41.99	-45.62	-45.11	-41.47	-31.29
30	-33.91	-33.84	-32.60	-43.95	-37.30	-42.25	-45.81	-45.36	-41.70	-31.42
31	-33.91	-33.84	-32.51	-44.48	-37.53	-42.32	-45.82	-45.37	-41.74	-31.31
32	-33.92	-33.85	-32.27	-45.94	-38.29	-42.73	-46.01	-45.41	-41.73	-31.52

POWER RATIO=(RECEIVER POWER/XMTR OUTPUT POWER) IN DB.

Case 2, Transmitter in Stub 14

POWER RATIO AT RECEIVERS (DB)

RECEIVER	COMBINED	** HARMONIC ** 1	3	5	7	9	11	13	15	17
1	-30.08	-30.01	-29.27	-35.71	-34.49	-40.57	-44.93	-46.59	-43.76	-33.93
2	-30.06	-29.99	-29.34	-24.59	-33.57	-40.15	-44.63	-46.38	-43.63	-33.92
3	-30.01	-29.97	-29.37	-32.59	-32.94	-40.07	-44.68	-46.66	-43.79	-33.37
4	-29.95	-29.94	-29.11	-31.08	-32.02	-40.43	-44.74	-46.27	-43.55	-33.75
5	-29.83	-29.89	-28.35	-29.57	-33.42	-39.55	-44.65	-46.66	-43.65	-33.75
6	-29.75	-29.84	-27.96	-29.21	-32.77	-37.69	-44.75	-46.13	-43.43	-33.67
7	-29.65	-29.79	-27.46	-28.50	-31.70	-34.74	-44.25	-46.19	-43.60	-33.65
8	-29.45	-29.65	-27.09	-25.89	-31.39	-34.81	-44.61	-46.35	-43.45	-33.56
9	-29.32	-29.58	-26.65	[illegible]	-31.57	-34.56	-44.52	-45.76	-43.53	-33.59
10	-29.09	-29.44	-26.70	-24.51	-31.67	-37.14	-43.96	-46.37	-43.79	-33.42
11	-28.81	-29.27	[illegible]	-23.33	[illegible]	-37.30	-44.37	-45.12	-43.48	-33.45
12	-28.41	-28.99	-26.12	-21.94	-30.40	-37.49	-44.21	-46.25	-43.37	-33.40
13	-28.27	-28.89	-25.96	-21.57	[illegible]	-37.14	-45.30	-45.28	-43.32	-33.42
15	-28.32	-28.39	-25.35	-22.05	-30.55	-37.72	-44.64	-45.42	-42.60	-33.36
16	-28.45	-28.97	-25.91	-22.34	-30.60	-39.04	-44.95	-45.23	-42.59	-33.32
17	-28.72	-29.17	[illegible]	-22.51	-30.94	[illegible]	-45.15	-45.32	-43.28	-33.46
13	-28.93	-29.33	[illegible]	-24.75	-31.95	[illegible]	-44.74	-45.86	-43.34	-33.53
19	-29.39	-29.59	[illegible]	[illegible]	-32.13	-33.53	-45.12	-45.49	-43.24	-33.52
20	-29.52	-29.31	[illegible]	[illegible]	-32.55	-34.35	-45.41	-45.39	-43.48	-33.65
21	-29.80	-30.04	-26.55	-27.56	-32.59	[illegible]	-44.94	-46.11	-42.56	-33.53
22	-30.00	[illegible]	-26.71	[illegible]	-32.44	-40.71	-44.90	-45.65	-43.53	-33.78
23	-30.22	-30.34	[illegible]	-30.00	-32.55	-40.15	-45.61	-45.34	-42.94	-33.61
24	-30.37	-30.43	-28.20	-31.45	-33.13	-39.59	-45.10	-45.17	-43.48	-33.90
25	-30.46	-30.47	-28.74	-32.62	-33.76	[illegible]	[illegible]	-45.57	-43.35	-33.75
26	-30.53	-30.51	[illegible]	[illegible]	-34.17	-40.31	-45.35	-45.76	-43.02	-33.90
27	-30.55	-30.52	-29.40	[illegible]	-34.19	-41.00	-45.59	-45.04	-43.19	-34.02
28	-30.59	-30.57	-29.74	-35.15	-33.95	[illegible]	-45.65	-46.26	-43.58	-34.01
29	-30.65	-30.55	-30.13	-37.79	-34.37	-40.56	-45.40	-45.91	-43.25	-34.06
30	-30.66	-30.57	-30.03	-39.15	-35.14	-40.34	-45.59	-45.17	-43.49	-34.12
31	-30.67	-30.57	-30.05	[illegible]	-35.40	-40.93	-45.60	-46.18	-43.53	-34.07
32	-30.70	-30.60	[illegible]	-40.55	-35.23	-41.35	-45.30	-46.23	-43.51	-34.13

POWER RATIO=(RECEIVER POWER/XWTR OUTPUT POWER) IN DB.

Case 3, Transmitter in Stub 14

POWER RATIO AT RECEIVERS (DB)

	COMBINED	** HARMONIC ** 1	3	5	7	9	11	13	15	17
RECEIVER										
1	-26.38	-26.27	-27.87	-30.94	-37.20	-45.24	-46.44	-38.65	-32.63	-28.31
2	-26.38	-26.27	-28.04	-31.28	-37.13	-43.74	-43.72	-36.09	-30.99	-27.62
3	-26.39	-26.27	-28.22	-30.41	-34.08	-39.69	-40.47	-35.31	-32.02	-28.16
4	-26.37	-26.27	-27.94	-28.87	-32.31	-38.76	-39.45	-33.96	-29.63	-27.30
5	-26.29	-26.23	-26.89	-27.66	-31.92	-35.84	-36.37	-32.90	-31.03	-27.18
6	-26.21	-26.18	-26.24	-27.72	-31.16	-34.70	-35.12	-31.51	-27.95	-26.91
7	-26.10	-26.09	-25.77	-27.84	-29.79	-32.48	-32.08	-28.66	-28.43	-26.89
8	-25.88	-25.90	-25.29	-26.56	-27.56	-29.50	-29.74	-28.99	-27.69	-26.99
9	-25.74	-25.76	-25.17	-25.74	-27.19	-28.86	-28.78	-27.35	-26.44	-26.06
10	-25.50	-25.53	-25.07	-24.87	-26.11	-26.05	-25.13	-24.29	-26.72	-26.32
11	-25.18	-25.21	-24.86	-24.21	-24.10	-23.53	-23.10	-24.53	-25.67	-25.55
12	-24.69	-24.74	-24.25	-23.44	-22.52	-21.63	-21.18	-22.45	-26.03	-26.43
13	-24.50	-24.56	-24.01	-23.31	-22.54	-21.15	-20.11	-21.53	-24.89	-24.91
15	-24.46	-24.51	-23.86	-23.32	-23.24	-21.19	-20.18	-21.92	-24.15	-28.12
16	-24.59	-24.65	-23.95	-23.45	-23.58	-22.22	-21.65	-23.27	-24.69	-27.01
17	-24.91	-24.97	-24.15	-24.00	-24.08	-23.95	-24.46	-26.31	-26.53	-26.65
18	-25.19	-25.24	-24.29	-24.62	-24.46	-24.45	-25.01	-26.58	-27.21	-29.46
19	-25.80	-25.87	-24.46	-25.77	-26.97	-28.28	-28.63	-28.32	-27.98	-27.49
20	-26.00	-26.08	-24.49	-25.80	-27.63	-29.11	-29.73	-29.27	-27.59	-29.06
21	-26.41	-26.50	-24.77	-26.18	-29.38	-31.73	-32.44	-30.61	-29.20	-28.30
22	-26.71	-26.78	-25.17	-26.88	-29.89	-33.47	-34.50	-31.97	-29.36	-29.40
23	-27.01	-27.04	-25.91	-28.35	-30.94	-35.45	-36.71	-33.95	-29.66	-28.84
24	-27.18	-27.17	-26.64	-29.38	-32.92	-37.39	-38.62	-34.25	-31.56	-29.72
25	-27.26	-27.23	-27.24	-29.76	-35.00	-39.91	-40.94	-35.13	-29.58	-30.49
26	-27.32	-27.26	-27.90	-29.92	-36.21	-43.66	-45.63	-39.22	-31.27	-28.92
27	-27.33	-27.26	-28.14	-30.05	-36.12	-44.06	-46.79	-40.88	-33.02	-29.39
28	-27.36	-27.27	-28.62	-30.80	-36.43	-44.34	-47.17	-41.17	-34.82	-31.47
29	-27.37	-27.25	-29.07	-33.15	-39.56	-48.07	-50.19	-41.87	-33.21	-30.05
30	-27.35	-27.23	-28.90	-33.57	-40.91	-50.42	-53.30	-44.53	-35.42	-31.51
31	-27.34	-27.23	-28.82	-33.59	-41.27	-50.96	-53.92	-44.87	-35.54	-31.82
32	-27.35	-27.24	-28.62	-33.44	-42.28	-53.89	-57.55	-47.31	-36.30	-31.72

POWER RATIO=(RECEIVER POWER/XMTR OUTPUT POWER) IN DB.

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